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Investigative Study of Simulation Techniques and Navigation Problems for the Arctic Marine Environment

Summary Report

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INVESTIGATIVE STUDY OF SIMULATION TECHNIQUES AND NAVIGATION PROBLEMS FOR THE ARCTIC MARINE ENVIRONMENT

- SUMMARY REPORT -

TP 4340E

February 1983

by

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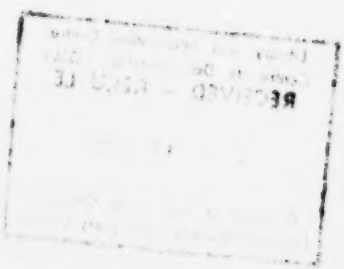

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17. Abstract

An investigation was conducted to examine the feasibility of developing Canada's capability to simulate ship navigation in ice-infested waters. Surveys were conducted to obtain the views of ship operators and owners regarding the usefulness of simulators and a number of open water ship simulators operating in various countries were reviewed. The requirements for ice navigation simulators are discussed and the quality and quantity of the available data base are presented. Methods of obtaining the derivative coefficients of the ship maneuvering equations are discussed and the model scale and full scale tests required are detailed. An overall comparison of cost between open water and ice-capable simulators is given. A tentative programme required to achieve this capability is presented.

The report recommends that information on model and full scale ship trials be gathered before an operating simulation facility is set up, and that a specific plan is necessary in order to achieve capability in ice navigation simulation.

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17. Résumé

Ce rapport rend compte des résultats de l'enquête menée par les auteurs pour déterminer si le Canada était en mesure de développer un simulateur de navigation maritime en eaux chargées de glace. Armateurs et capitaines ont été interrogés sur l'utilité des simulateurs de manoeuvre, et un certain nombre d'appareils conçus dans divers pays pour la simulation en eau libre ont été examinés.

Les auteurs abordent la question des aptitudes et caractéristiques à attendre des simulateurs de navigation dans les glaces et font une appréciation qualitative et quantitative des bases de données disponibles à l'heure actuelle dans ce domaine. Ils exposent aussi différentes méthodes pour l'obtention des dérivés utilisées dans les équations de mouvement servant à la simulation des manoeuvres, ainsi que les essais en bassin et en eau libre nécessaires à cette fin. Par la suite,ils comparent les coûts globaux de la première catégorie de simulateurs à ceux de la deuxième. Enfin, ils proposent un project de programme de recherche devant mener au développement d'un simulateur de conception canadienne.

En conclusion, le rapport fait deux recommandations, à savoir: 1) mener d'autres essais sur modèles réduits et en vrai grandeur avant de monter un simulateur opérationnel et 2) élaborer un plan d'action précis si l'on veut que le développement d'un simulateur de navigation dans les glaces puisse se concrétiser.

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Marine, glace de mer, navigation maritime, manoeuvre, simulateur, essais sur modèle réduit	Le CDT dispose d'un nombre limité d'exemplaires.

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FOREWORD

The Government of Canada through Transport Canada has recognized the potential of marine navigation simulators to further the knowledge of ship operations in the Canadian Arctic and to provide basic training to the masters of ice-going ships.

The need and form of such a capability is, however, not currently established. Such factors as whether emphasis should be placed on training or research and development, the degree of complexity of the facility, the costs and utilization are still to be determined. One consideration does, however, appear to be generally agreed, and that is, that with many adequate open water facilities in existence offshore, a suitable specialization for a potential Canadian facility could include navigation in ice, a capability which is not currently available elsewhere.

This background was in place when Arctec submitted an unsolicited proposal to carry out preliminary investigations which would assist in the decision-making process. It was proposed to investigate the extent of the data base for simulating navigation of ships in ice and to assess the practicality, equipment implications and research requirements of establishing such a facility.

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1. INTRODUCTION

Two basic requirements perceived for the capability and versatility of ice-related marine simulators are training and research, and it is understood that the two aspects will be shared by the Canadian Coast Guard (CCG) (training) and the Transportation Development Centre (TDC) (research). It is obvious that these studies must not proceed in isolation from each other and that marine simulation in Canada would benefit if the simulators eventually established were compatible with each other.

An ice-capable-simulation facility in Canada must be capable of reproducing, in an accurate manner, the motions and responses of ships in Arctic and sub-Arctic ice as well as in ice-free and partially ice-covered waters. It must also, ideally, be capable of reproducing the behaviour of ice when acted upon by the presence of and motions of a ship.

The simulators must be capable of modelling ships of varying types and sizes such as ice capable VLCCs, large and small icebreakers, down to the smallest ice capable support and supply vessels. To achieve this objective it will be necessary to develop a reliable data base of Arctic and sub-Arctic ice and the operational behaviour of these ships in such ice. This data will be used to extract the "coefficients" for the equations of motion of the different ships under varying ice conditions. A limited quantity of such data exists and more will have to be obtained by dedicated and systematic full scale and model scale testing.

Examination of a number of open water simulators shows that there are three main types providing sophisticated computer generated images, television pictures of scaled gaming areas and simple bird's-eye-view representation on a cathode ray tube. The mathematical models used vary in complexity depending upon the degrees-of-freedom modelled and whether rudders, thrusters, tugs, etc. are included. Training simulators, in general, tend to provide more elaborate audio-visual effects than research simulators. The cost of the different types of simulators varies from a low of $250K to more than $10M. The amount and quality of out-of-window simulation accounts for a large portion of the total cost. (The costs quoted are in 1980/1981 dollars).

The "simple" math models simulate forward and astern movement of the ship with standard engine and helm orders and often without tug assistance for docking, etc. Examples of this type are simulators operated by the Glasgow College of Nautical Studies and the Pacific Marine Training Institute at Glasgow and Vancouver respectively. The more sophisticated research simulators, on the other hand, with their attendant complex mathematical and image reproduction models, are capable of simulating additional incidents such as shallow water and bank effects, push and pull forces of tugs, multiple propellers (including thrusters) and rudders, physical motion of the simulated bridge, emergencies such as engine and rudder failure, grounding, collision, etc. Examples of this type are the CAORF, SUSAN and CASSIM simulators.

As a research tool an ice-capable simulator will aid in the study of the following types of problems:

- validation of and improvements to mathematical models for ship maneuvering (operation) in ice-infested waters.
- development of operational strategies under normal as well as hazardous ice and weather conditions.
- design of ports and harbours particularly with regard to the most effective use of icebreakers for maintaining ice-free channels, approach routes, location of docks, dredging requirements, etc.

2. DISCUSSION

2.1 Maneuvering of Ships in Ice

The requirements imposed on the simulation of ship maneuvering are extremely diverse. They encompass not only such fundamental aspects as resistance, propulsion and steering, but also ice conditions, which substantially complicate calculations of maneuvering. Analysis of maneuverability in ice is in the initial stages of development and hence does not yield a reliable calculation procedure that can be adapted to simulations. It has been established that despite theoretical instability on course, icebreakers during independent movements in ice exhibit operational stability on course. The latter is evaluated by statistical means of the periods and amplitudes of vessel yaw and periods and angles of rudder deflection. Among the most important characteristics of operational stability on course are the average frequency of rudder deflection and the average angle of rudder deflection under various ice conditions. During continuous motion in level uniform ice, the amplitudes of yaw of the vessel are small (less than one degree). It is not known at present if there is a definite relationship between course stability and ice thickness. However, the operational course stability of any vessel is known to be substantially worse in irregular (in terms of thickness and strength) hummocky ice and in floe ice than in level uniform ice. Under such conditions the angle of yaw of the vessel reaches as high as 40 to 50 degrees.

It is clear from the above discussions that from the view points of both maneuverability and course-keeping ability, the major modes of ship motion that will have to be addressed at length are the surge, sway, yaw and roll. Detailed equations of motion can be developed and computer programs formulated for simulation of ship maneuvering in ice. A level I flow diagram of such a program is shown in Figure 1.

In order to simulate any icebreaking maneuver however, it is necessary to have available an adequate amount of reliable ice-related data.

The primary source of data for simulating navigation in ice is model scale tests of each ship (or class of ship). This is the commonly followed procedure for all ship related work, since model testing, in addition to being cheaper, can be conducted under better control than full scale trials. The results of full scale ship trials are then used to validate the model scale data. Some of the more significant data parameters and the reasons for their requirements are shown in Table 1. The data can be categorized into two groups:

- data from ice trials with the ship (or model) proceeding straight ahead - provides values of ice resistance, i.e. ice thicknesses that the ship is capable of breaking in the continuous mode while going ahead at various speeds.

FIGURE 1: GENERAL FLOW DIAGRAM OF MANEUVERING COMPUTATIONS

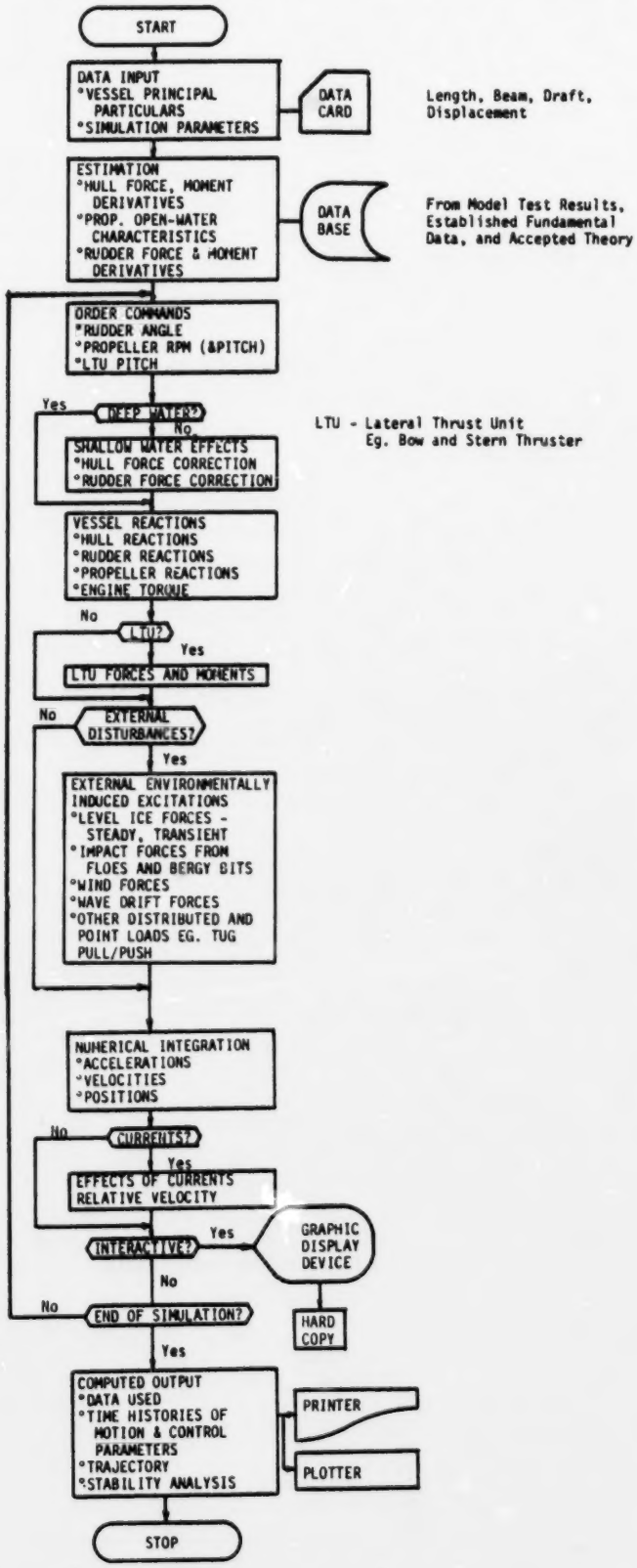


TABLE 1

REQUIREMENT OF FULL SCALE AND MODEL SCALE DATA

PARAMETERS	APPLICATION
SHIP - body plan	Provides the bow geometry which affects the icebreaking pattern and energy imparted to the ice
- principal particulars	Identifies the ship type and enables manufacture of geometrically similar model.
SHIP STABILITY PARTICULARS - roll period, pitch period, metacentric height, etc.	Affects ship's turning capability in ice
WINDAGE AREA - projected areas of freeboard and super structure	"
RUDDER(S) - area, cross-section, centre of pressure, etc.	Determines the capability of the rudder(s) to turn the ship
RUDDER ANGLES USED	Provides the turning moment applied to the ship
PROPELLER(S)- diameter, no. of blades, shape and profile, fixed or controllable pitch, etc.	Provides information on the thrust and torque that can be developed by the propellers in ahead and astern modes and for stopping and starting the ship
PROPELLER THRUST, TORQUE AND RPM	Provides information on the power delivered to move the ship
MAIN PROPULSION MACHINERY: SIZE AND NUMBER OF ENGINES	Provides the power available (i.e. developed horsepower)
TYPE OF ENGINES - steam, diesel, gas turbines, electric, etc.	Affects engine response time and stopping distances
REDUCTION GEARING	Affects ahead to astern response time
THRUSTERS	Affects ship's turning capabilities at slow speeds and when stopped.
SHIP SPEED	Provides information on the power delivered to move the ship

TABLE 1 continued

PARAMETERS	APPLICATION
ICE - level,floes,bergy bits, etc.,amount of cover, first year,multi-year, consolidated, etc.	Affects the visual presentation as well as ship/ice interaction characteristics
ICE THICKNESS, STRENGTH, MODULUS, ETC.	Provides information on resistance to steady motion in level unbroken ice
HULL/ICE FRICTION COEFFICIENT	"
SNOW COVER	"

- data from maneuvering trials in ice - provides results of turning circle trials and zig zag maneuvers in terms of advance, transfer, tactical diameter, etc. at specified ship speeds, rudder angles and ice thicknesses as well as derived values of drift angle, rate of turn, etc.

No standardized methods exist for obtaining data on ship-ice interaction in other modes such as interaction with ice floes, edge of an ice shelf or impact with bergy bits, etc. Collection of this type of data will require special methods and dedicated trials.

Model and full scale ice resistance data collected from a variety of sources, with vessels proceeding straight ahead, has been recently reanalyzed by Arctec. The availability of this data is shown in Table 2. The overall full scale ice resistance data is considered to be the most extensive in the western world. Model scale ice resistance data for the CCGS PIERRE RADISSON provides enough data, to accurately predict the ice resistance and validate the prediction with full scale results.

Model and full scale trials conducted to measure maneuvering characteristics of ships in ice have been examined and the quality and quantity of data published has been found to be limited.

The best documented full scale turning data is for the CCGS PIERRE RADISSON and consists of seven turning circle trials with ice thickness data available for five of these trials. The total range of results available for the RADISSON and other ships is shown in Table 3 and Figure 2. The alpha numeric numbers against the data prints in Figure 2 indicate left or right rudder and the degrees of rudder employed.

As indicated earlier, full scale results are used mainly to verify the accuracy of model experiments. The paucity of full scale results, therefore, does not necessarily mean that model results will not be acceptable but merely that they will need to be validated.

Table 4 shows the vessels for which model scale experiments have been conducted to determine their maneuvering and directional stability characteristics. It can be seen that the ice data available for the earlier tests is not as complete as for the tests carried out in 1982. Some of the data, such as hull-ice friction and Young's Modulus of ice was not available in the reports but is probably available in the working papers of those trials. Measuring the crushing strength of ice is a recent addition to the parameters and as such will not be available for the earlier tests. In the more recent tests the models were self propelled and so the propeller particulars are available. Of the twelve available model results, only the POLAR VIII, VIIIA, VIIIB and VIIIC trials were conducted without rudders. Rudder particulars for the other models should therefore be available in the working papers for the cases where they are not given in the published reports.

TABLE 2

AVAILABLE ICE RESISTANCE DATA														
SCALE		PARAMETER	SHIP											
			MAN-HATTAN	MACKI-NAW	KATMAI BAY	RADISSON	ST. LAURENT	A. HENRY	WOLFE (NEW BOW)	STATEN ISLAND	ARCTIC	VLADI-VOSTOK	FINN-CARRIER	JELPARRI
FULL SCALE	ICE TRIALS	T_B	✓		✓	✓	✓	✓						
		Q_B	✓	✓	✓	✓			✓	✓	✓	✓	✓	
		N_B	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		V_S	✓	✓	✓	✓	✓	✓	✓	✓	?	✓	✓	✓
		H	✓	✓	✓	✓	✓	✓	?	✓	✓	✓	✓	✓
		σ_f	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓
		SNOW	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		μ		✓	✓	✓	✓		✓					
MODEL SCALE	RESISTANCE (ICE)	R		✓	✓	✓	✓	✓				✓	✓	✓
		V_S		✓	✓	✓	✓	✓				✓	✓	✓
		h		✓	✓	✓	✓	✓				✓	✓	✓
		σ_f		✓	✓	✓	✓	✓				✓	✓	✓
		μ			✓	✓	✓	?				✓	✓	✓
	SELF PROPELLED (ICE)	T_B	TANK TESTS DONE AT WÄRTSILÄ, BUT DATA NOT AVAILABLE.			✓				✓				
		Q_B				✓				✓				
		N_B				✓				✓				
		V_S				✓				✓				
		h				✓				✓				
		σ_f				✓				✓				
		μ				✓								

T_B THRUST (BEHIND)

Q_B TORQUE (BEHIND)

N_B PROPELLER SPEED

V_S SHIP'S SPEED

H ICE THICKNESS

σ_f FLEXURAL STRENGTH OF ICE

SNOW SNOW COVER

μ HULL ICE FRICTION COEFFICIENT

R HULL RESISTANCE IN ICE

V_S MODEL SPEED

h ICE THICKNESS

? QUESTIONABLE DATA

TABLE 3
AVAILABILITY & QUALITY OF MODEL SCALE MANEUVERING DATA

TABLE A2.3

		MODEL PARAMETERS																									
		VESSEL						RUDDER			TEST RESULTS									PROPELLERS			ICE				
		L	B	T	C_B	LCG	V_C	AREA	X-SECT	CTR OF PRESS	X	Y	N	V_{TOW}	ARM LGTH	r	β	δ	d	N	K_T	h	μ	σ_f	σ_c	E
	PARAMETRIC MODELS																										
1975	MODEL 1	✓	✓	✓	✓	✓		✓	CHORD & SPAN	*	G	G	G	G	G	G	G	G	NOT REQUIRED FOR THIS TEST			G	*	G		*
	MODEL 2	✓	✓	✓	✓	✓		✓	"	*	G	G	G	G	G	G	G	G		"		G	*	G		*
	MODEL 3	✓	✓	✓	✓	✓		✓	"	*	G	G	G	G	G	G	G	G		"		G	*	G		*
	MIND CLASS																										
1975	LABRADOR 1	✓	✓	✓	✓	✓		✓	CHORD & SPAN	✓	G	G	G	G	G	G	G	G		"		G	*	G		*
	LABRADOR 2	✓	✓	✓	✓	✓		✓	"	✓	G	G	G	G	G	G	G	G		"		G	*	G		*
	CAPTIVE MODEL TESTS																										
1980	Hull 719	✓	✓	✓	*	*		*	*	*	G	G	G	G	NOT FOR THIS TEST	REQ'D FOR THIS	*	G	✓	G	THRUST	G	*	G		*
	HULL 718	✓	✓	✓	*	*		*	*	*	G	G	G	G		"	*	G	✓	G	"	G	*	G		*
	POLAR CLASS																										
1982	POLAR VIII	✓	✓	✓	✓	*		NOT REQUIRED FOR THIS TEST			F	F	*	G		"	F	NOT REQUIRED FOR THESE TESTS	✓	G	THRUST	G	G	G	G	G
	POLAR VIIIA	✓	✓	✓	✓	*			"		F	F	*	G		"	F		✓	G	"	G	G	G	G	G
	POLAR VIIIB	✓	✓	✓	✓	*			"		F	F	*	G		"	F		✓	G	"	G	G	G	G	G
	POLAR VIIIC	✓	✓	✓	✓	*			"		F	F	*	G		"	F		✓	G	"	G	G	G	G	G
1982	POLAR VIII RUDDER CONFIG.	✓	✓	✓	✓	*		*	*	*	NOT REQUIRED FOR THIS TEST		G		NOT USED IN THIS TEST	G	G		✓	G	"	G	G	G		G

LEGEND:

✓ - available
* - not given in the report, but probably available
G,F,P - data quality: good, fair and poor, respectively

VESSEL

L - Length on WL or LBP
B - Moulded Breadth
T - Mean Draught
C_B - Block Coefficient
LCG - Distance of (longitudinal) centre of gravity from ⊕ or FP.
V_C - Critical speed, below which the ship will not turn in a given thickness of ice.

RUDDER

X-SECT - NACA rudder section shape
CTR OF PRESS. - distance of rudder centre of pressure from the rudder post or leading edge

TEST RESULTS

X, Y - Force in the direction of motion and normal to the direction of motion, respectively
N - Yaw moment
V_{TOW} - Velocity of model(ship) in the direction of motion (i.e. carriage velocity)
ARM LGTH - Length of the rotating arm during model turning tests
r - Velocity of rotation of the model
β - Drift angle
δ - Rudder angle

PROPELLERS

d - diameter of propeller
N - propeller RPM
K_T - Thrust coefficient

ICE

h - thickness of ice
μ - coefficient of friction between ice and hull surface
σ_f - flexural strength of the ice
σ_c - crushing strength of the ice
E - Young's modulus of the ice

FIGURE 2

TURNING CIRCLE DATA FOR ICE-CAPABLE SHIPS

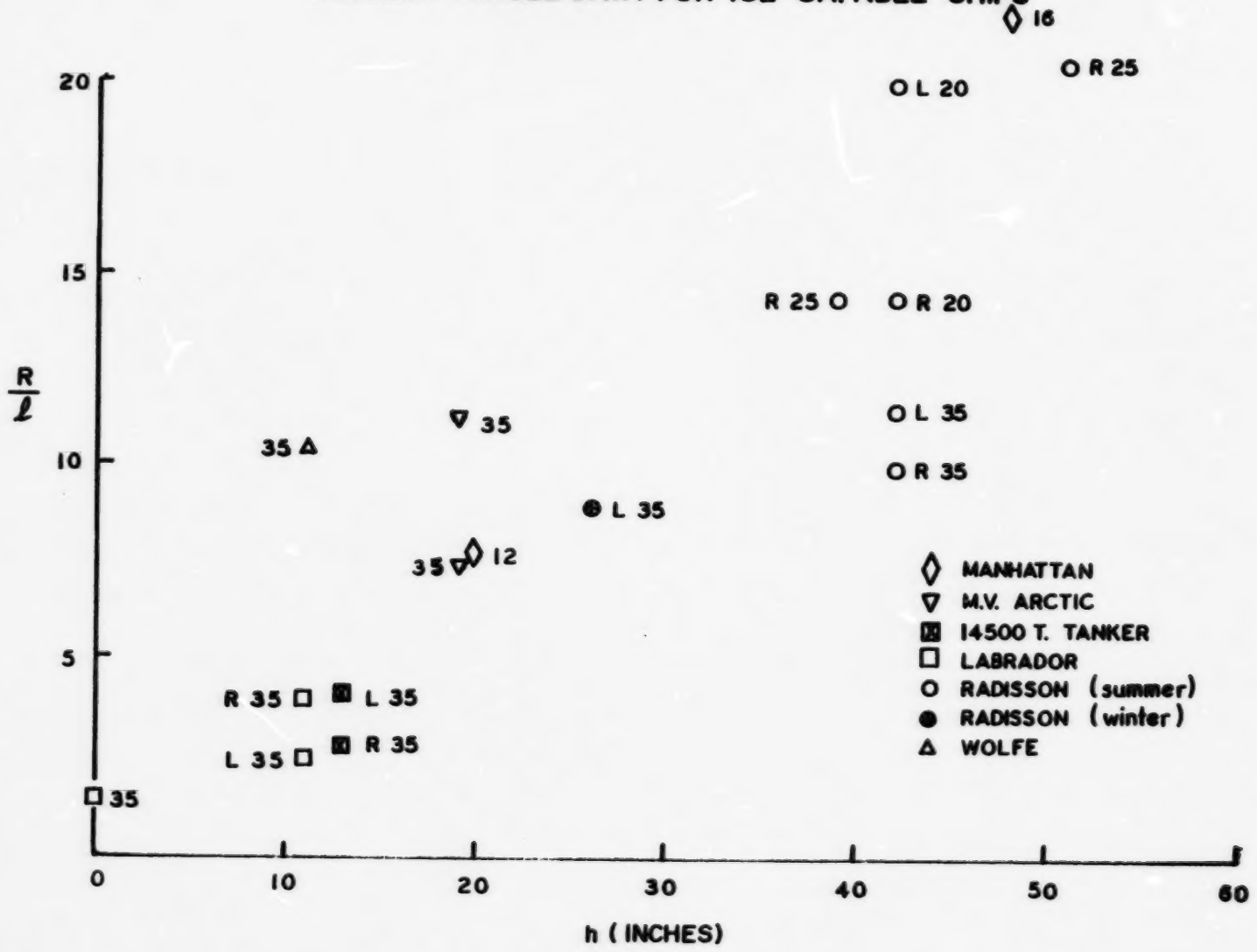


TABLE 4: COMPARATIVE TURNING CIRCLE DATA FOR ICE CAPABLE SHIPS (FULL SCALE)

VESSEL	LBP ft	RUDDER ANGLE °	TURN RADIUS ft	R/L	ICE THICKNESS in/m	DEPTH OF SNOW in/m	ICE BENDING STRENGTH psi/kPa	ICE RESISTANCE (at v = 0) lbs	BOLLARD THRUST lbs	RESISTANCE (v = 0) / BOLLARD THRUST
RADISSON	288	35 R	3951	14		0/0	≈30/208	100,000	282,000	.35
			6079	21						
RADISSON	288	35 L	3647	13	39/1.0	0/0	≈30/208	100,000	282,000	.35
RADISSON	288	35 R	2871	10	39/1.0	0/0	30/208	100,000	282,000	.35
RADISSON	288	20 R	4053	14	39/1.0	0/0	30/208	100,000	282,000	.35
RADISSON	288	20 L	5877	20	39/1.0	0/0	30/208	100,000	282,000	.35
RADISSON	288	35 L	2280	7.92	26/.66	4.1/.11	69/475	106,000	282,000	.38
LABRADOR	334	35 R	988	4	11/.28	0/0	?	30,000	230,000	.13
LABRADOR	334	35 L	628	2.5	11/.28	0/0	?	30,000	230,000	.13
WOLFE	220	35	2420	11	11/.28	.6/.12	?	42,000	60,000	.7
MANHATTAN	1005	10 -12	7920	7.88	4"-48"/.11.2	—	Weak	?	?	?
MANHATTAN	1005	10 -16	22000	21.89	Thick&Thin	—	Mixed	?	?	?
ARCTIC	623	35 (?)	Min 4801 Mean 7106	7.7 11.4	19"/.48 Estimated	1.25/.03 Estimated	?	?	?	?
14.5 K DWT TANKER (Gulf of Bothnia)	485	35 R	1406	2.9	13/.33	0/0	Level ice & small ridges	?	?	?
		35 L	2037	4.2	13/.32	0/0		?	?	?

In general, it is considered that it would be possible to extract coefficients for the equations of motion for all the models listed in Table 4. However, since validation of model scale maneuvering results with full scale data is, at present, possible only for the LABRADOR, the simulation required for this phase of this project, has been carried out for the LABRADOR.

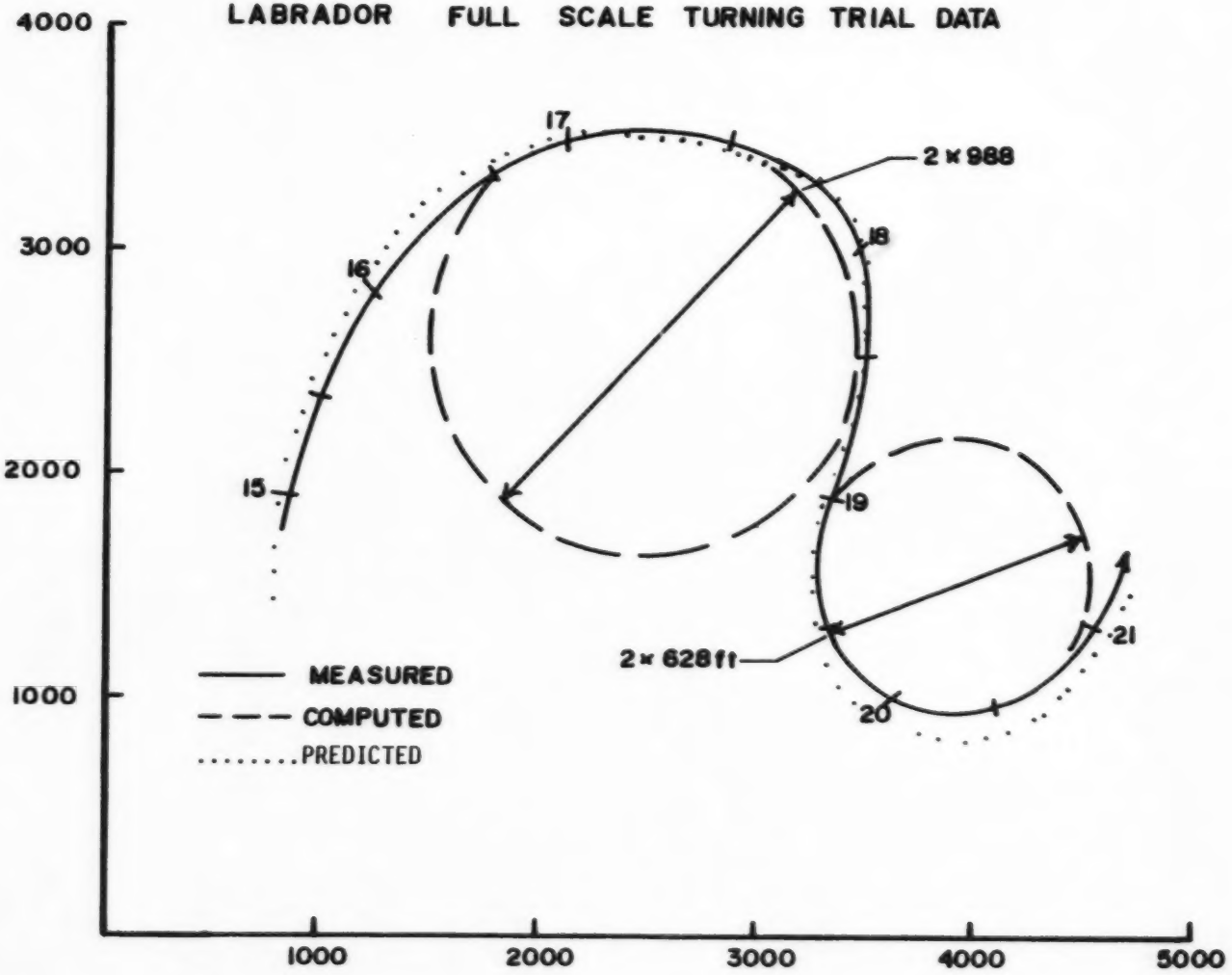
CCGS LABRADOR turning tests were conducted south of Lowther Island, in October 1973. The ice on the turning course was on the average one foot thick with occasional first year pressure ridges. The tests were run at full power with the rudder in the hardover position. Two steady turns - one right hand and one left hand, were performed at ship speeds of 12.7 knots and 10.1 knots respectively. The full-scale turning trajectory data for LABRADOR is shown in Figure 3. The turning circles were drawn in so as to fit the turning trajectory and the diameters were estimated using a graphical method. These are also shown in Figure 3. Table 5 shows the measured vessel speed and rudder angle settings used in the simulation.

TABLE 5 - LABRADOR FULL SCALE TURNING DATA

TIME (minute)	SPEED (ft/sec)	RUDDER ANGLE (degree)	POSITION (x.ft)	(y.ft)
15.0	22.0	-5.0	921	1934
15.5	21.6	-8.0	1044	2355
16.0	22.1	-15.0	1222	2821
16.5	22.4	-25.0	1757	3345
17.0	22.6	-35.0	2178	3517
17.5	23.0	-35.0	2915	3506
18.0	22.3	-20.0	3472	3034
19.0	20.1	-5.0	3381	1911
19.5	17.2	10.0	3354	1308
20.0	16.0	35.0	3626	986
20.5	17.8	35.0	4239	1046

The turning path predicted by the approximate scheme is shown in Figure 3 as dotted lines. It is seen that the predictions agree fairly well with the measurements in the case of the starboard turn. In the port turn, the predictions result in a slightly larger turning circle than the measured one. It is believed that the assumption of uniform level ice conditions and rough approximation of rudder response time contributed to the discrepancy. Further refinements in the description of the ice field and the availability of more precise steering gear characteristics are expected to improve the accuracy of the predictions.

FIGURE 3


LABRADOR FULL SCALE TURNING TRIAL DATA
4000
3000
2000
1000
1000
2000
3000
4000
5000
15
16
17
18
19
20
21
2 × 988
2 × 628 ft
MEASURED
COMPUTED
PREDICTED

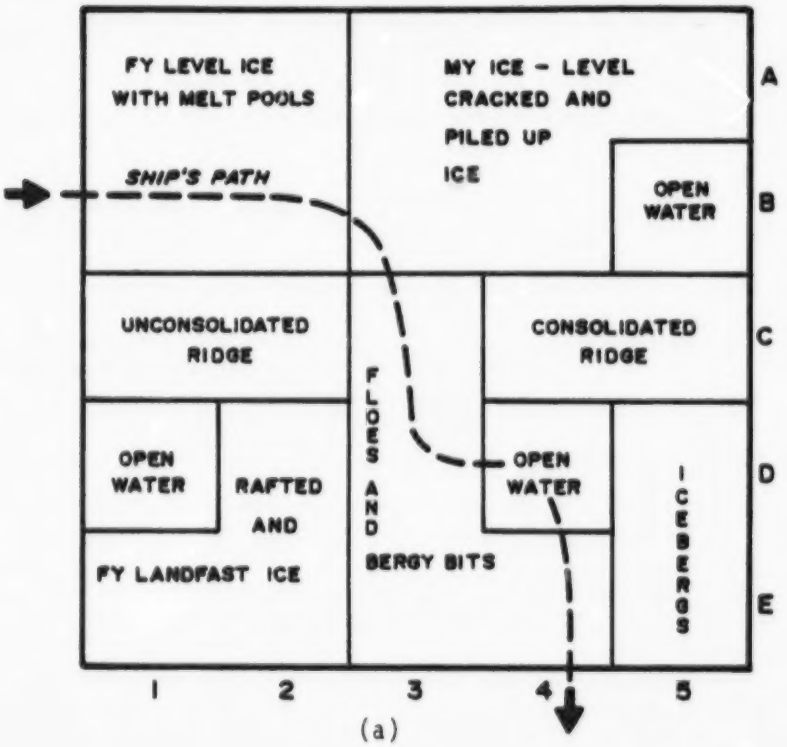
The problem of simulation of vessel movement in a general ice environment is complex owing to the large number of parameters required to describe the process. In order to simplify the situation, approximate descriptions amenable to simple mathematical expressions are required. An example of such a situation is shown in Figure 4(a). The ice field has varying descriptions at various locations, but the variations are across clearly defined boundaries. Such a "grid" arrangement may be made more coarse or more fine depending on the accuracy required in the simulation. Simulation of vessel movement in each area will now be based on uniform ice conditions and properties. For example, in area B-1, the vessel is in first year ice with melt pools. Calculation of ice forces will, therefore, be based on derivative coefficients evaluated from model tests in uniform level ice with melt pools. When vessel movement occurs at the border between B-3 and C-3, calculations will be based on data corresponding to multi-year ice with cracks and pile up. In areas C-3 and D-3, impacts against floes will be simulated. In D-4, open water coefficients will be used.

Arrangement of the above "gaming area" is strictly based on geographic and climatic conditions. But the vessel's route will be determined by ship's ice-worthiness, power, maneuverability and also the captain's decisions.

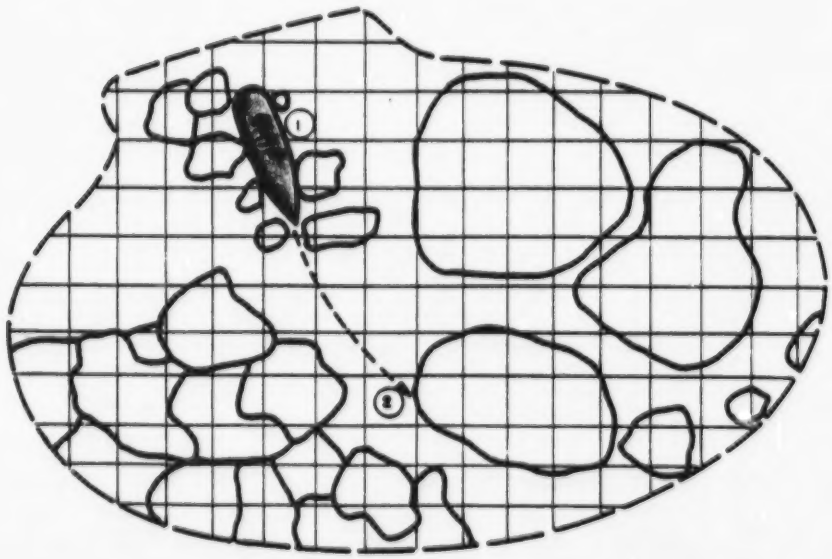
In the event maneuvering among floes is to be simulated, a finer grid arrangement will be adopted as shown in Figure 4(b). Of interest is the method of simulating the movement of the vessel from position 1 to position 2. At 1, the vessel will attempt to move steadily ahead, as the floes obstructing the path are fairly small. Each of these floes, on impact against the hull generates a force pulse of finite magnitude having a short duration. At the end of the impulse, the floe mass will add to the inertia of the hull in the various modes of motion and also increase the viscous resistance of the hull until the floe is "pushed" out of the way. As the vessel approaches 2, the captain will attempt to maneuver the vessel so that contact with the large closely packed field of floes is avoided, but nudge the large single floe on the port side. The impact should be large enough to either fail the floe edge sufficiently to allow passage or to push the floe aside. The effect of the rudder forces and propeller thrust are dominant in the open-water area between 1 and 2. On impact at 2, the crushing and bending forces of the ice will dominate. The equations are amenable to (time) step-wise computation and are easily programmed. Head-on impact, oblique impacts and jamming between floes can be simulated using the basic methods of computation of ice forces.

FIGURE 4

A GENERAL ICE ENVIRONMENT LAYOUT AND VESSEL ROUTE



(a)



(b)

A TYPICAL MANEUVERING SCENARIO

2.2 Scenarios Meriting Studies by Simulation

Responses from ship operators indicate that many of the problems of navigating ships in ice may be overcome or made less critical by studying them on ice capable simulators. Examples of present and foreseeable scenarios that would benefit from such studies are given below:

a) Scenarios that could benefit from simulated study in the immediate future.

   i) Ship's Behaviour: Studying the turning characteristics, stopping distances, accelerating capabilities (particularly from the stopped condition), etc. when operating under all possible ice conditions likely to be encountered in the ship's operating zones.

   ii) Combined Operations: Following in the track of an icebreaker at various speeds and distances abaft the icebreaker. The size and percentage cover of the ice floes in the broken channel may be varied.

   iii) Navigating under conditions of poor visibility with instruments only. The simulations would study not only the use of various types of radar, radio, etc. but also the layout of the equipment on the ship's bridge as well as shape and size of the bridge, for efficient operation.

   iv) Navigation in confined areas such as inlets and harbours. Simulation of such areas and repeated "runs" with various ship-types would provide training to ship operators as well as design information for research purposes on the layout of harbours and channels.

   v) Ship handling: Training junior officers by giving them practice in shiphandling under simulated conditions as often as necessary until a specific standard of competence has been achieved.

b) Scenarios that could benefit from simulated studies in the foreseeable future.

   i) Operation of large vessels: Simulated operation of large ice-capable ships such as VLCCs, under various combinations of ice, weather, visibility, channel conditions, etc. to provide data on their operating capabilities, restrictions, and limitations before such vessels are permitted to operate in ice covered waters.

   ii) Port and Harbour Design: Designs of harbours, berthing arrangements within the harbours, approaches to the harbours, etc. especially under conditions when the water is frozen, may be studied by using experienced pilots to carry out simulated navigation in these areas under all possible combinations of ship operation (including system failures) and environmental conditions.

iii) Ship Safety: Simulated ships' systems failures (e.g. loss of rudder, damage to propellers, failure of one or more main engines), fire, collisions, etc. especially in restricted ice covered channels, may be studied singularly or in combination of two or more incidents. Repeated studies of this type would provide valuable data for producing new or amending existing safety regulations.

iv) Evaluation of Sensors: Simulation of the output of new sensors (such as side scanning sonar) and studying the information provided and methods of presentation in comparison with existing sensors would permit evaluation of the new equipment without requiring dedicated ship trials and personnel aboard the ship to carry out the trials.

v) Interaction of Propellers and Rudders with Ice: Simulation of propeller/ice milling incidents to study the propeller RPM, thrust and torque fluctuations as well as ice impingement forces on the rudder particularly with the rudder at positions other than amidships and the ship going astern would provide information on the vulnerability of propellers and rudders.

2.3 Ability of Data Base to Meet Requirements

The data available from full scale and model scale tests and trials do not cover all the scenarios described in Section 2.2. The deficiencies fall into two categories and may be expressed as those in the data base applicable specifically to ice or those that can be made good by adapting open water simulation procedures. The two categories are summarized below.

a) Data base deficiencies applicable specifically to ice:

(i) Force and moment coefficients for steady turning in homogeneous level ice. (Available at present for a few icebreaker hull forms only).

(ii) Force data for transient operations (e.g. backing and ramming, commencing a turn, etc.)

(iii) Forces resulting from interaction with ice floes.

(iv) Forces and moment coefficients for ice-strengthened hulls (as opposed to icebreaker hull forms) in thin level ice and in ice floes.

(v) Extrapolation of data to other hull forms.

(vi) Propeller- and rudder-ice interaction forces.

b) Deficiencies that can be overcome by adapting open water simulator procedures:

(i) Reduced visibility and blind (or instrument) navigation.

(ii) Port and harbour navigation and design.

(iii) Generating emergencies and testing ship safety.

(iv) Evaluation of sensors.

2.4 Methods of Rectifying the Deficiencies

The rectification of the deficiencies may be achieved in two stages: in the near future and in the long term.

a) Near future remedies:

(i) Develop a scheme for interpolation (and extrapolation) of level ice force coefficients to other hull forms. Such a scheme would allow simulation of steady movements of a larger range of vessels in uniform level ice.

(ii) Liaise with open water simulator operators (or acquire open water simulator programs) to develop methods for adapting routines for reduced visibility, blind navigation, generation of emergencies, simulation of sensor outputs, etc., for use in an ice-capable ship simulator.

b) Long Term Remedies:

(i) For ship handling and ship behaviour scenarios covering operations such as steady turning ahead and astern, backing and ramming, navigating regions containing ice floes, etc., it will be necessary to conduct the following model tests. The tests will be conducted in a systematic manner so as to envelope the scenarios as well as the hull forms of icebreakers and ice-strengthened vessels.

°Captive model and rotating arm tests

°Free-running self propelled model tests

°Towed tests (i.e. not self propelled) of two-dimensional models where the length dimension is kept constant and the beam to draught ratios and dead-rise angles are systematically varied.

The captive and free-running model test results will provide force and moment coefficients for the specific vessels tested. The two-dimensional model tests will provide force data for different types of hull forms.

(ii) Simulation of ship safety is directly related to emergencies which can be generated by adapting open water simulation techniques. The outcome of each of these emergencies and hence the safety in ice covered waters, is likely to be quite different from that in open water. For example: loss of one propeller (of a twin propeller vessel) would cause a ship operating in open water to lose speed, tend to turn toward the damaged propeller side, require excessive helm and possibly an alteration of the propeller RPM to maintain course. In ice-covered waters, however, one shaft alone may be unable to develop enough power for the ship to break ice and the ship may thus stop. Such scenarios will require systematic model tests, described earlier, for each type of emergency envisaged for all types of hull forms being studied.

(iii) Port and harbour navigation is equivalent to navigating in confined areas in ice-covered waters. This simulation will require operating data in the form of force and moment coefficients for level ice and floes, steady turning, backing and ramming, etc., obtained as detailed above. Once this data is available for the type of hull form being simulated, repeated systematic runs will provide data on the safest and/or best course, speed, propeller and rudder usage, etc. to be employed under the specific ice conditions to reach the required destination.

(iv) Design of ports and harbours is the counterpart of navigation in ports and harbours in that the same information and data will be required, but the simulations will be conducted with a view to improving the harbour rather than achieving the best course and path to navigate in a specified harbour.

(v) Simulation of propeller-ice milling and rudder-ice interactions will require conducting model tests to acquire data on the force, moment and torque coefficients for these interactions. Mathematical models will then be developed to permit application over a wide range of ice conditions, hull forms, rudder and propeller particulars, ship speeds, etc. The model test results and mathematical formulations will require validation with full scale results. Full scale data will be obtained by using ships of opportunity as well as carrying out specific trials with dedicated ships.

3. REVIEW OF SIMULATORS

A total of fifteen open-water simulators were surveyed. Their particulars are given in Table 6.

TABLE 6

SIMULATORS

NAME	COMPUTERS	DISPLAY	INCIDENTS	BRIDGE MOTION
1. SUSAN (German) (Initial cost ≡$7.5M)	Central 1 x PDP 11/60 16 bit, 128K core +2x4000K disc + 2 x 8k tape Peripheral 13 x Krupp EPR 1100 16 bit, 64K +8000K disc	CGI 11 colour TV proj. 250° azimuth 19° vertical Dynamic Sea Surface (to show wind, swell, etc.) (≤ 4000 edges!)	Numerous; executed via a menu-guided keyboard	± 5° mechanical ±10° visual
2. MARIN (Wageningen Netherlands (Initial cost not known)	CENTRAL 1 x PDP 11/44 1 x PDP 11/34 Peripheral 3 x RKO 5 1 x RLO 2 1 x RSO 4	Vector General 23" 360° Azimuth Apparently on a 23" TV screen! Point light source outside view	Emergencies Tug pull Bow Thrusters executed via control switches	Two interactive bridges but no bridge motion
3. SSPA (Goteborg Sweden) (Initial Cost Not Known)	Central SEL 32/57;EAI hybrid sys.(i.e.2xEAI 680+2 x EAI693 +1 x PACER 100). 512KB; 64KB and Anal.eq.	CGI +internal TV, both black and white using line elements and Navaid Characteristics ±40° from aft steering stand ±70° from for'd consoles(all apparently on TV screens in the windows) Also synthetic radar providing O/H views of own ship and area	Emergencies • Tug pull mooring lines thrusters Either randomly or manually generated	No bridge motion

TABLE 6 continued

NAME	COMPUTER	DISPLAY	INCIDENTS	BRIDGE MOTION
4. CASSIM (Cardiff Wales) (Initial cost more than $10M)	For CGI PDP 11/34 4M byte storage For equations of motion and bridge control Kongsberg KS 500 + PDP 11 ≙ 123K bytes storage.	CGI "Tepigen" Marconi System (≙2000 faces) Azimuth 120° Vertical 30° (Expansion of Azimuth to 200° is planned.)	Emergencies, tug pull, mooring lines, bow thruster etc. executed via the instructor's console	Vibration, own and other ships' sounds, sirens, bells, etc.
5i.Glasgow College of Nautical Studies (Existing) (Initial cost $1M)	Kongberg KS 500 for ship motion storage 64K	Night time view on bridge window (large C.L) Azimuth 100°	Emergencies, tug pull, mooring lines, Bow thrusters executed via "push buttons" on the instructor's console	Engine and prop. noise, vibration of deck.
	Note: All equipment and facilities housed in 2 "Porta Cabins".			
5ii. Glasgow College of Nautical Studies (expected to complete late 1982) (Initial cost ≙ $0.4M)	NORD 10/S	Little information available but is expected to be similar to the present simulator.		
6.Marine & Technical College S. Shields (Initial cost = $1.35M)	RACAL DECCA RDS 500 64K storage	Night view on bridge window Azimuth 100°	Emergencies, tug pull, mooring lines Bow Thrusters executed via the instructor's console	Deck Vibration

TABLE 6 continued

NAME	COMPUTERS	DISPLAY	INCIDENTS	BRIDGE MOTION
7.Hydronautics Inc. Laurel,MD. (Initial cost ≈$0.25M)	PDP 11/44 to be replaced by VAX 750 in May 82	Line dwg. display on CRT (can be TV projection) ± 40 Azimuth but adjustable to look at full 360°	Emergencies, Tug pull Mooring lines, Bow & Stern thrusters. executed via the instructors console	No bridge motion.
8. CAORF National Maritime Research Centre Kings Pt. New York (Initial cost not known)	The computers comprise a Central Data Processor an Image generator & a Display unit.	CGI view through wheel-house windows Azimuth ±120° Vert.: +10 to -14 Daylight to moonless night	Emergencies Tug pull, Mooring lines, Bow thruster, etc. executed via the instructors console	No bridge motion.
9. MITAGS Lethicum Heights,MD (Initial cost not known)	MA COM 32	View on screens Full 360 visual system! (seamless screens) one day and one night. Maps, photographs & scale models are converted to film format & projected on to a spherical screen around the bridge. Separate systems project the ship's forebody, contact vessels, water and clouds.	Emergencies Tug pull, Mooring lines Bow thruster etc. executed via the instructor's console	Bridge roll, pitch & heave. Also sound.
10. I.H.I. (Initial cost ≈ $1M)	Yamatake - Honeywell Co. Computer Y-316 24 Kw core 204 Mw disc	Full colour 4 slide projectors 1 movie projector 100 Azimuth ±30 Vertical	None indicated but it is expected that all standard emergencies and incidents can be generated	No bridge motion indicated
11. MSI (La Guardia Airport) New York (Initial cost not known)	1 x Univac V77 2 x PDP 11 1 x HP 10 x APPLE (for various simulators)	3-D models with for'd and astern TV probes. 150° For'd view 40° Astern view ("Model Boards" are 15 ft x 30 ft.)	Emergencies, Tug pull, Mooring lines, Bow thrusters, etc. executed via the instructor's console	No bridge motion or sounds.

4. FACTORS AFFECTING ICE NAVIGATION SIMULATORS

4.1 Factors Affecting Navigation in Ice

Ships operating in ice-infested waters are subject to the normal forces, motions and hazards of sea going ships in addition to those created by ice. Some of the more important of these factors are:

- °ship's icebreaking capabilities
- °ship's turning capabilities in ice
- °vulnerability of propellers to propeller-ice interaction
- °vulnerability of rudders to rudder-ice interaction
- °escorted operations
- °physical and mechanical properties of ice
- °visibility
- °snow cover
- °leads and cracks in the ice.

4.2 Rating of Factors Affecting Ice Navigation

The factors listed in Section 4.1 are rated against the primary building blocks of a simulator in Table 7. The symbols used in the table are:

L - low
M - medium
H - high
VH - very high
UH - ultra high
CPU - Central Processing Unit

Table 8 shows comparative costs of simulators. It can be seen that a Cardiff type ice-capable simulator may cost three times as much in hardware and ten times as much in software (man years) as an MSI type ice simulator.

TABLE 7

RATED REQUIREMENTS OF COMPONENT CAPABILITIES FOR SHIP SIMULATION IN ICE COVERED WATERS

	CPU	PROJECTION	IMAGE GENERATION	RADAR	INSTRUCTOR CONSOLE	BRIDGE
Icebreaking Mode	H	H	VH	L	L	M
Turning and Maneuvering	VH	VH	UH	L	L	M
Propeller Ice Interactions	H	n/a	n/a	n/a	M	M
Rudder Ice Interactions	H	n/a	n/a	n/a	M	M
Escorted Operations	VH	UH	UH	M	M	M
Ice Properties	M	M	VH	H	L	L
Visibility	H	H	H	H	L	M
Snow Cover	M	M	H	H	L	M
Leads in Ice	VH	VH	VH	L	L	L
COST OF CARDIFF TYPE						
Proportion of hardware ($)	2%	7%	78%	13%		
Proportion of software (MY)	5%	0	94%	1%		
COST OF MSI TYPE						
Proportion of hardware ($)	6%	18%	38%	38%		
Proportion of Software (MY)	45%	0%	45%	10%		

TABLE 8

COST ESTIMATES (HARDWARE DOLLARS, MAN-YEARS)
FOR OPEN WATER VERSUS ICE SIMULATORS

	CPU				PROJECTION				IMAGE GENERATION				RADAR				TOTALS			
	OPEN WATER		ICE		OPEN WATER		ICE		OPEN WATER		ICE		OPEN WATER		ICE		OPEN WATER		ICE	
	H$	MY	H$	MY	H$	MY	H$	MY	H$	MY	H$	MY	H$	MY	H$	MY	H$	MY	H$	MY
CARDIFF (Wales) Cost	200K	5	300K	10	500K	0	1M	0	6M	50	12M	200	1M	1	2M	2	7.7M	56	15.3M	212
% of Total	2.5	9	2	5	6.5	0	7	0	78	89	78	94	13	2	13	1				
MSI (New York) Cost	200K	5	300K	10	500K	0	1M	0	1M	5	2M	10	1M	1	2M	2	2.7M	11	5.3M	22
% of Total	7	45	6	45	19	0	18	0	37	45	38	45	37	10	38	10				

Note: The cost of a CARDIFF type ice simulator is three times the hardware and ten times the software of a MSI type ice simulator.

5. RESEARCH AND DEVELOPMENT REQUIREMENTS

5.1 Model Scale Tests

Several experimental methods may be employed to determine the ship's maneuvering characteristics in ice. They include the planar motion mechanism (PMM) method, the oscillator method, the drift angle method and the rotating arm method. The PMM and oscillator methods are expensive and involve intricate analysis techniques. The other two methods are therefore considered more suitable.

In the straight-line tests the models are towed at constant velocity along a straight line parallel to the basin with a drift angle varying between -3 and 12 degrees. This straight-line towing of a model with a drift angle generates a transverse velocity component and thus provides the data to plot the forces and moments against the transverse speeds. The distance of travel for each run is about two ship lengths. In the rotating tests, the models are towed along an arc segment by the rotating arm. This rotation generates a pure yaw angular velocity in the model. The rotating tests thus provide the data to plot the longitudinal forces and moments versus the yaw angular velocity. The two methods are shown diagramatically in Figure 5.

The following measurements are required during the tests:

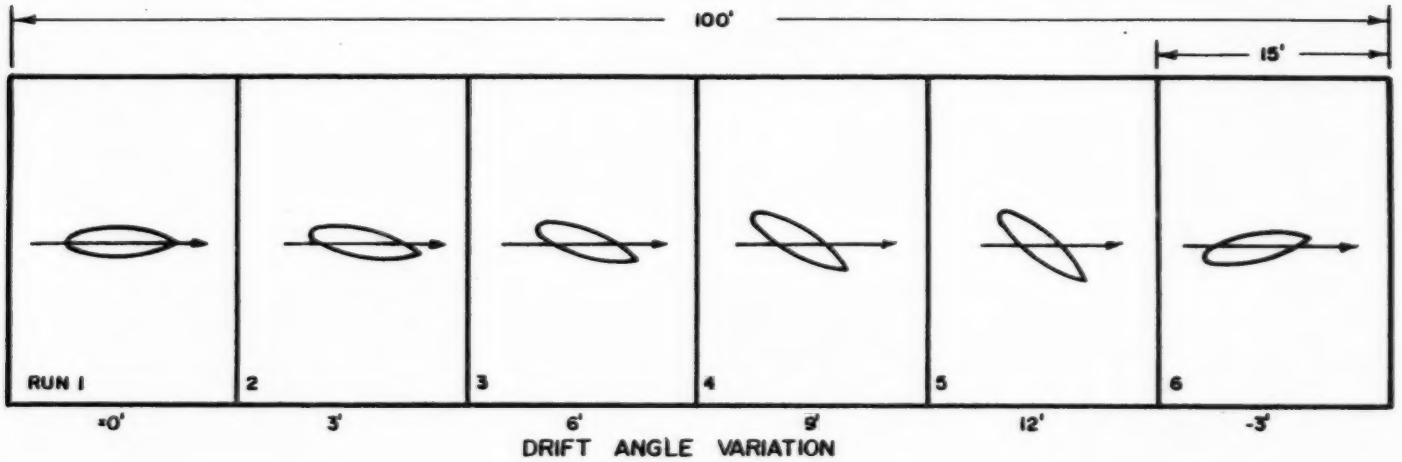
- Longitudinal and transverse forces on the hull
- Hull moment
- Forward speed of the towing carriage
- Rotating arm revolutions to calculate yaw angular velocity
- Drift angle
- Ice crushing (indentation) and bending strengths
- Ice thickness along model track.

5.2 Full Scale Tests

Model scale tests provide parameters such as fore and aft and athwartship forces on the hull, the yawing moment, the towing speed, etc., which are used to extract the force and moment coefficients required for simulating ship operations in ice covered waters. The validity of this simulation is ascertained by full scale tests. Full scale testing is expensive and must therefore be planned and executed in a systematic manner. At times, it may be desirable to conduct certain tests on an "opportunity" basis. For example: results of ship impact with ice floes of significant size may be obtained relatively inexpensively by availing of the opportunities presented to any ice capable or ice worthy ship in the vicinity of such a floe. Such ships of opportunity will need to be instrumented to gather the necessary information and the ship's staff instructed in testing procedures. Results of steady turn parameters such as, plot of turning circle, rate of turn, rudder angles used, etc. can only be obtained by using dedicated ships to conduct specific trials.

FIGURE 5

TYPICAL STRAIGHT LINE AND ROTATING TEST SEQUENCE



5.3 Other Factors

5.3.1 Sound and Visual Presentation

The visual simulation of an ice environment is undoubtedly a most difficult task. There are two basic problem areas in ice simulation. They are:

- The development of an image generation technique to simulate the shading and textures of ice (i.e. multi-year, first year, ridging, open track).
- The development of an image generation controller to keep the image generation rate high as well as to remember the look of an ever changing gaming area.

5.3.2 Strategies for Emergency and Ship Safety

Items related to emergencies and ship safety may be divided into the following categories:

- Failure of primary control equipment
- Failure of non-control equipment
- Damage
- Environmental factors

Events in some categories can be related to similar events in open water and experience of open water simulators used to advantage. Other events such as a vessel beset in ice (environmental factors) have no open water parallel and may therefore require model and full scale tests to obtain enough data points to enable simulation.

5.3.3 Simulation of Ports and Harbours

Numerous open water simulators have programs for simulating existing as well as proposed ports and harbours. The simulated harbours are then used as the gaming areas for navigation in ice-free but restricted waters as well as for berthing and docking purposes with and without the help of tugs and thrusters.

Ports and harbours whose waters are prone to freezing can be similarly modelled as gaming areas by using the technique suggested in Section 2.1. The modelling will include all waterways and channels, all obstructions and navigational aids, the shoreline including land marks within the harbour, and other effects such as ship-shore interaction, tides, currents, wind, tugs, etc. It will also model the ice and snow conditions inside the harbour and alongside the docks jetties. Before any ice modelling can be done, however, it will be necessary to collect full scale data on the ice build up within these areas.

6. CONCLUSIONS

An overwhelming majority of operators of ships in ice infested waters have responded favourably toward the establishment of an ice capable ship navigation facility in Canada. Many of them, however, insist that unless the simulator is capable of very realistic sound, vibration, picture and motion generation, its usefulness as an aid to research and ice navigation training will be limited.

Present day ice-free water simulators are capable of simulating navigation of practically any size of ship, in harbours and confined waters, with and without tug assistance, including effects of wind and tide and system failures of various kinds. Many of them are also used for research into development of ports and harbours and investigation of accidents. Some of them have good quality visual and audio presentation while others have simple plan view presentation on Cathode Ray Tubes and video screens. None of them, however, has the capability to simulate ship navigation in ice. Various types of simulator facilities and the degree of sophistication of each will need to be studied to achieve a balance between what is required and how much it will cost.

Although the data base for simulating ships in open water is fairly extensive, there are vast basic deficiencies in the data base for simulation of ships in ice. Examples of these deficiencies are:

- Force and moment coefficients (i.e. the derivative coefficients) for equations of motion are available for a very limited number of icebreakers for straight line motion and steady turning in homogeneous level ice only. Each set of derivative coefficients must be developed for a specified ice thickness, strength, cover, etc., and a specified condition of loading for the ship being simulated.

- No data is available on the forces and moments during backing and ramming.

- Very little data exists on methods for mathematical modelling of ship/ice-floe interaction.

- No force coefficients are available for ordinary ice strengthened vessels operating in thin ice.

- There are no techniques available, at present, for extrapolating known coefficients to other hull forms.

- No data exists on the operation of large vessels such as VLCC's in ice infested waters.

- Very little data exists on mathematical and physical modelling of propellers operating in ice.

A number of techniques and methods employed in simulation of ships in open water can be readily adapted for application to ice capable simulators. Examples of such cases are:

- Port and harbour design. To adapt techniques from ice free water port and harbour design, it will be necessary to be able to simulate ship operation in ice-covered restricted waters.

- Ship Safety. Techniques for generating ship related emergencies in ice free waters would be directly applicable. However, the ship's response to those emergencies would be ice related.

Systematic ship model tests in model scale ice are essential for obtaining data for simulation. These will consist of tests for icebreaker hulls, as well as ice-strengthened hulls and will include:

- Ice resistance tests.

- Straight line tests with drift angle variations.

- Rotating arm tests.

- Free running self propelled model tests.

- Towed models of fixed lengths but systematically varying beam to draught ratios and dead-rise angles.

The first four tests will result in force and moment coefficients for the specific vessel hulls tested while the last will provide force data for different hull types.

The behaviour of the propellers and rudders in an ice environment will require model scale tests. These tests will be conducted to obtain force, moment and torque coefficients for propeller/ice and rudder/ice interactions. These parameters will then be used to develop mathematical models to permit application to cases other than those tested.

The simulator outputs obtained by using model tests and mathematical formulations will require validation with results obtained from full scale tests. These tests may be carried out either with dedicated ships or with ships of opportunity, depending on the type of test.

7. RECOMMENDATIONS

The following recommendations are made:

°The operational requirements of the simulator be defined. For example:

(i) Areas of vessel operation that are likely to be simulated, viz. Lancaster Sound, Barrow Strait, regions of Baffin Bay, certain harbours, etc.

(ii) Types of incidents likely to be simulated, viz. ship operations in various ice conditions, ice bustles in docking areas, poor visibility, etc.

(iii) Whether the simulator will be used primarily for research or training or both.

(iv) What the cost limitations are likely to be, because this, more than any other single factor, will dictate the degree of realism that can be attained.

It may be advisable to purchase a small proprietary OW simulator and adapt it to simulate ships in ice before developing (or procuring) a simulator with a relatively high degree of realism. One such simulator is the COMPUSIM MARINE SIMULATOR.

Advantage be taken of every opportunity to gather full scale information of ice-capable vessels. In this respect, a number of CCG icebreakers are deployed regularly in Canadian Arctic waters. The USCGC POLAR SEA which is due to carry out trials in the Antarctic region presents one excellent opportunity. The ice in this region consists mainly of relatively thick level ice (an occurrence less common in the Arctic) and any data collected under such conditions would be valuable in validating model scale data on similar types of ships.

Figure 6 is a proposed outline of a program to achieve a capability in ice navigation simulation. Because the schedule is part of a feasibility study it has been drawn up in general terms and does not apply to any specific vessels or time period. As may be expected, the first year of the plan is more detailed than the subsequent period.

Figure 6

Outline of a Program to Achieve
a Capability in Ice Navigation Simulation
(Time in Weeks)

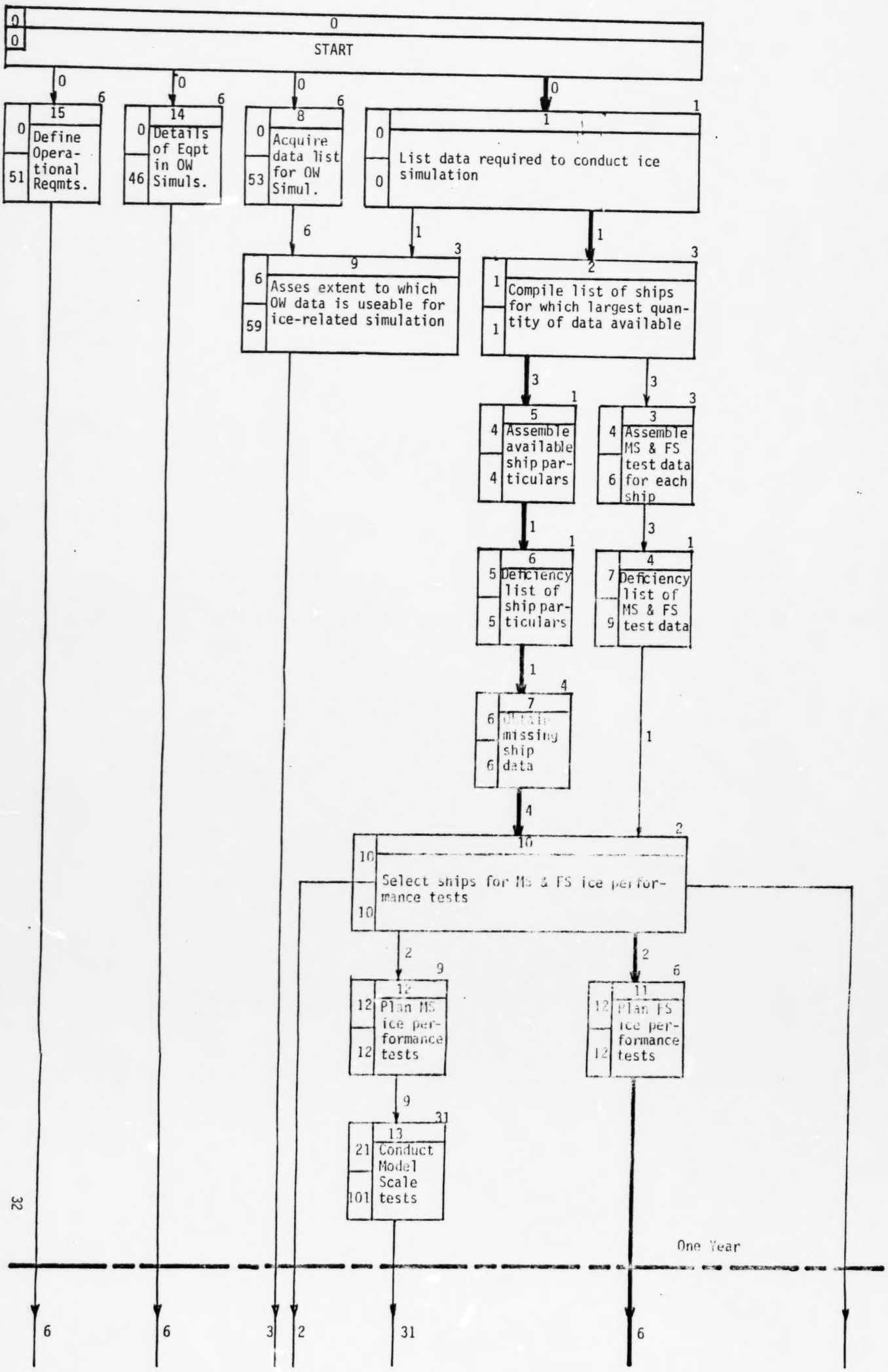

START
Define Operational Reqmts.
Details of Eqpt in OW Simuls.
Acquire data list for OW Simul.
List data required to conduct ice simulation
Asses extent to which OW data is useable for ice-related simulation
Compile list of ships for which largest quantity of data available
Assemble available ship particulars
Assemble MS & FS test data for each ship
Deficiency list of ship particulars
Deficiency list of MS & FS test data
missing ship data
Select ships for MS & FS ice performance tests
Plan MS ice performance tests
Plan FS ice performance tests
Conduct Model Scale tests
One Year

Figure 6 continued..